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Lesquerella press cake as an organic fertilizer for greenhouse tomatoes☆

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ABSTRACT

Lesquerella press cake is a co-product generated during the processing of the new oilseed crop lesquerella [*Lesquerella fendleri* (A. Gray) S. Wats.]. Developing commercial uses for the press cake would increase the profitability of growing lesquerella. The press cake contains levels of nutrients which should make it an excellent organic fertilizer for container-grown plants. Tomato (*Solanum lycopersicum* L. 'Red Robin') plants were grown in potting mix supplemented with a standard chemical fertilizer mix or either lesquerella press cake or cottonseed meal at rates of 2.5, 5.0 and 10.0% (w/w). Both of the organic fertilizers had only minor effects on the physical properties (bulk density, total porosity percentage, total solids percentage, pH, EC) of the potting mixes with increasing rates, although there was substantially less shrinkage of media amended with 5 and 10% press cake than with the same rates of cottonseed meal. At rates of 10.0% for press cake and 5.0% for cottonseed meal (which supplied similar substrate nitrogen levels), plant heights, total tomato yield per plant and number of fruit per plant were equal to that of the chemically fertilized control. There were no differences among treatments for average fruit weight. Chlorophyll content was generally similar among the treatments during the course of the experiments, with a trend towards lower values for the 2.5% rates of press cake and cottonseed meal near the conclusion of the experiments. From these results it appears that lesquerella press cake may be a useful organic fertilizer for container-grown tomatoes.

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1. Introduction

Lesquerella [*Lesquerella fendleri* (A. Gray) S. Wats.] is an oilseed crop belonging to the mustard family (Brassicaceae) that is being developed as a *new crop* for arid regions of the southwestern United States. Lesquerella oil is rich in hydroxy fatty acids (HFAs), which are important as industrial raw materials for making polymers such as nylon, resins, waxes, corrosion inhibitors, coatings, lubricating greases, and cosmetics (Dierig et al., 1992). Lesquerella oil contains 54–60% lesquerolic (14-hydroxy-*cis*-11-eicosenoic) and 3–5% auricolic (14-hydroxy-11,17-eicosadienoic) acids as the predominate HFAs (Hayes et al., 1995). Castor (*Ricinus communis* L.) oil is currently the main commercial source of HFAs, and is comprised of approximately 90% ricinoleic (12-hydroxy-9-octadecanoic acid) acid. Castor oil production in the U.S. has been almost completely eliminated due to a combination of economic factors, excessive allergenic reactions by field and processing workers, and the toxicity of the seed meal, also referred to as castor pomace, which contains the lectin ricin. In order to detoxify castor pomace, autoclaving the pomace at 125 °C for 10 min or longer is necessary (Kodras et al., 1949). Due to its HFAs, lesquerella could serve as a potential domestic replacement for imported castor oil. Unlike castor pomace, lesquerella press cake should have little or no toxicity issues. As Abbott et al. (1997) have noted, utilization of the residual press cake after processing will be instrumental in supporting the initial growing and processing costs associated with a new crop such as lesquerella. Although there is currently no commercial production, pilot plant scale lots of lesquerella seeds are processed by dry extrusion and expelling at our laboratory (Evangelista, 2009).

Container production of horticultural crops has increased rapidly in the last several decades. Container substrates used in horticultural crop production are principally organic materials such as peat moss and tree barks blended with other organic or inorganic components (Bilderback et al., 2005). Potting substrates utilizing naturally occurring materials such as peat, bark, coir, etc., supplemented with an organically based fertilizer would meet the criteria for producing plants as organically grown (Jones, 2008). The utilization of farm, industrial and consumer waste by-products has been extensively investigated (Chong, 2005). As a co-product of lesquerella processing, press cake could be a low-priced organic fertilizer/potting mix component for pot-grown vegetables and ornamentals. Tomatoes are the leading greenhouse vegetable crop

☆ Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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Table 1
Chemical properties of lesquerella press cake (LPC) and cottonseed meal (CM) (% w/w of dry material; average values of three replications).

	LPC	CM
Total N (%)	4.30	8.21
P (%)	0.73	1.43
K (%)	1.42	1.83
Ca (%)	0.79	0.27
Mg (%)	0.30	0.81
S (%)	1.50	0.48
Na (ppm)	128	109
B (ppm)	16	20
Cu (ppm)	6	12
Fe (ppm)	210	128
Mn (ppm)	17	26
Zn (ppm)	52	66

grown in the United States, although developing greenhouse production methods which can be certified as organic are difficult (Parker, 1989; Jones, 2008). Ideally, a production system in which all of the required essential elements (as fertilizers) were added to the mixes initially, with only watering subsequently needed, would appear to be simple and cost-effective. Additionally, an organic growing medium that did not require additional fertilization during the lifespan of the plant should be particularly attractive to home gardeners. A major disadvantage of organic crop production is the generally lower yields received compared to conventional chemical fertilization (Mäder et al., 2002). However, research by Rippy et al. (2004) suggested that harvest yields of greenhouse tomatoes produced organically were similar to those produced conventionally. The aim of the present study was to investigate the use of lesquerella press cake as an initial application, organic fertilizer for greenhouse tomatoes.

2. Materials and methods

2.1. Materials

Lesquerella seeds harvested in 2008 were supplied by Dr. David Dierig, USDA-ARS Arid Lands Agricultural Research Center, Maricopa, Arizona. The seeds were processed as described by Evangelista (2009) using a heavy duty laboratory screw press (Model L250, French Oil Mill Machinery Company, Piqua, OH). The resultant press cake was further processed into a coarse flowable powder using a Fritsch Rotor-Speed Mill Model VDE 0520 (Fritsch GmbH, Idar-Oberstein, Germany) fitted with a 4-mm screen. Substrate used in experiments was Redi-earth® Plug and Seedling Mix (Sun Gro Horticulture, Bellevue, WA, USA). The chemically fertilized control medium was supplemented with Osmocote® 14-14-14 and Micromax® chemical fertilizers (The Scotts Company LLC, Maryville, OH, USA) at rates of 23 and 3.5 g fertilizer/kg potting mix, respectively. Cottonseed meal was obtained commercially (The Espoma Company, Millville, NJ, USA). Lesquerella press cake (LPC) and cottonseed meal (CM) were dried in a 40 °C oven for 48 h prior to being incorporated into the potting substrate. Rates of LPC and CM of 2.5, 5.0 and 10.0% (w/w) were employed, as preliminary tests indicated that higher levels of both amendments caused growth reduction and/or phytotoxicity with tomato transplants. Analyses of total N, P, K, Ca, Mg, S (w/w) and Na, B, Cu, Fe, Mn, Zn (ppm) in the press cake and the cottonseed meal were conducted in triplicate samples using Association of Official Analytical Chemists methods by CLC Labs, Westerville, OH (Table 1). Tomato (*Solanum lycopersicum* L. 'Red Robin') seeds were purchased from Tomato Growers Supply Company, Fort Myers, FL, USA. This cultivar was chosen because of its determinate habit (plant growth stops after flowering is initiated allowing for end points for fruiting), dwarf plant size and lack of need for insect pollinators.

2.2. Physical characteristics of potting media

Physical properties of each media were determined by the methods of Spomer (1990) and Webber et al. (1999) for bulk density, percent solids and percent air porosity, while pH and electrical conductance (EC) were evaluated by the methods of Milford (1976) using a HI 9813 portable EC meter (Hanna Instruments, Woonsocket, RI, USA) and an AB 15 pH meter (Fisher Scientific,) using 1:2 volume water extracts. Shrinkage of the potting media was estimated as volume lost by the various media over the duration of the experiment after drying at 105 °C for 12 h (Bustamante et al., 2008).

2.3. Plant experiments

Tomato seeds were planted in control medium on January 2, 2009 and allowed to grow for 4 weeks, per standard practice (Jones, 2008). On January 30, 2009, seedlings were transplanted individually into 6.0-L pots filled with the different test potting media and placed in a greenhouse maintained at 28 °C, 16-h day/20 °C 8-h night utilizing both natural light and supplemental artificial lighting to maintain an average light intensity of approximately 600 μmol m^{-2} s^{-1}. Pots were spaced 25 cm apart (at this distance there was no overlap of leaf canopy and hence little light competition between plants) in a completely randomized design with six replicates. Change in plant heights were recorded for 7 weeks from transplanting, when further growth ceased. Fruit number per plant, total fruit weight per plant and average fruit weight were recorded. Fruit were harvested at the "red" harvesting stage, meaning that red color covered at least 90% of the fruit (Jones, 2008). Due to the determinate nature of 'Red Robin,' new flowering had ceased after about 10 weeks after transplanting, and all remaining fruit on the plants at 12 weeks after transplanting, whether completely ripe or not, were harvested. Because there was only a small percentage of fruit which had defects, no distinction was made concerning fruit grades. Chlorophyll content of plants was measured using a SPAD-502 chlorophyll meter (Konica Minolta Sensing, Inc., Tokyo, Japan), which measures chlorophyll content of the leaves and is linearly related to leaf nitrogen concentrations and therefore availability of nitrogen from the growing media (Yoder and Pettigrew-Crosby, 1995). SPAD readings were taken from the most terminal fully expanded leaves weekly from transplanting until fruit harvest commenced, at which time it became very difficult to take further readings.

2.4. Statistical design and analyses

A Completely Randomized Design experiment with 6 replications was conducted comparing the mean values of 7 treatments in single-factor ANOVAs for plant height, number of fruit per plant, total fruit weight per plant, and average fruit weight of greenhouse tomatoes. Levene's homogeneity of variance test was not significant for plant height, number of fruit per plant, or average fruit weight, indicating no transformation of the data was necessary. A significant result was obtained for total fruit weight per plant ($p = 0.0426$), and the transformation (total fruit weight per plant)^2 stabilized the variance so that an ANOVA could be calculated. Differences of least squares means was used as the multiple comparison test when significant F-test values were obtained from the ANOVAs at $p \leq 0.05$. All analyses were performed on transformed data where necessary but raw data are presented for ease of interpretation. The Bonferroni (Dunn) t-test at the 0.05% significance level was used to calculate LSDs for physical properties of growing media and SPAD values. All statistical analyses were performed using SAS Version 9.1.3 (SAS Institute, Inc., Cary, NC, USA).

Table 2
Physical properties of growing media used.

Growth media component	Bulk density ($g\,cm^{-3}$)	pH	EC ($dS\,m^{-1}$)	Total porosity (%)	Solids (%)	Shrinkage (% vol)
Control	0.170c	5.2b	0.39c	78.8a	21.2c	19.3d
2.5% lesquerella press cake	0.215b	5.2b	0.36c	73.1b	26.9b	19.6d
5.0% lesquerella press cake	0.229a	5.3ab	0.55b	71.4c	28.6ab	21.0cd
10.0% lesquerella press cake	0.239a	5.4a	0.67a	70.1c	29.9a	23.3c
2.5% cottonseed meal	0.205b	5.3ab	0.50b	74.4b	25.6b	22.0c
5.0% cottonseed meal	0.211b	5.3ab	0.54b	73.6b	26.4b	26.5b
10.0% cottonseed meal	0.213b	5.4a	0.63a	73.3b	26.7b	29.1a

Different letters within columns for each variable indicate significant differences between treatments (Bonferroni *t*-test at $\alpha = 0.05$).

Table 3
SPAD[a] values for treatments.

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Control	50.9b	51.3a	60.6a	55.1ab	57.0a	51.1b	53.2bc
2.5% lesquerella press cake	53.3ab	51.2a	45.9c	48.5c	47.1c	48.3c	46.4d
5.0% lesquerella press cake	54.6a	52.0a	54.2b	52.2b	49.0bc	50.5b	52.3c
10.0% lesquerella press cake	49.6b	48.1a	56.9b	45.1d	50.0bc	48.3c	55.6b
2.5% cottonseed meal	48.0b	48.4a	46.9c	58.1a	51.3b	49.8bc	48.7d
5.0% cottonseed meal	48.9b	52.2a	55.2b	53.0b	55.9a	50.4b	50.0c
10.0% cottonseed meal	54.9a	52.2a	64.1a	56.0ab	57.5a	56.0a	59.0a

Different letters within columns for each variable indicate significant differences between treatments (Bonferroni *t*-test at $\alpha = 0.05$).
[a] SPAD values are measurements of leaf chlorophyll and are proportional to leaf nitrogen concentrations.

3. Results and discussion

3.1. Chemical and physical characteristics of the growing media

LPC used in experiments had an initial pH of 5.6, an EC of 2.72, and a moisture content of 6.0% (w/w), while CM had a pH of 6.3, an EC of 3.04, and a moisture content of 7.5% (w/w). The chemical analyses of LPC and CM used in this study are shown in Table 1. LPC had only about half of the nitrogen that CM contained, with slightly lower levels of phosphorus and potassium. The nitrogen value for the CM used in this study was approximately 1–2% higher than is normally reported with CM (Rodale, 1959). However, LPC had a threefold higher level of sulfur than the CM, possibly due to high levels of the glucosinolate glucoiberin [3-(methylsulfinyl)propylglucosinolate] or degradation products in the seedmeal (up to 6.5% weight of the seedmeal) (Vaughn and Berhow, 2005). Despite the high level of sulfur, none of the LPC treatments developed detectable off-odors, which are oftentimes a problem when utilizing organic wastes in potting mixes, although some off-odors were detected in the 10.0% CM treatment pots. Due to high temperatures used during processing for the oil, the major secondary chemical present in lesquerella seed, glucoiberin, is degraded primarily into the compound iberin nitrile, which is polar and has little or no odor (MacLeod et al., 1981; Vaughn and Berhow, 2005). This high processing temperature also inactivates the enzyme myrosinase (β-thioglucosidase glucohydrolase; EC 3.2.3.1), preventing further enzymatic hydrolysis of residual glucoiberin into iberin [1-isothiocyanato-3-(methylsulfinyl)propane] which is highly volatile, has a pungent, irritating odor, and is toxic at fairly low levels (VanEtten and Tookey, 1983).

Several physical properties of the different growing media are shown in Table 2. Bulk densities of LPC-supplemented media were higher at all rates used than media with CM. Only slight differences for initial pHs in the media were found, while the ECs of the media increased with raising rates of supplements, although at much lower values than occurred with various composts or olive-mill wastes when added at similar rates to potting media (Papafotiou et al., 2004; Chong, 2005). Total porosity percent decreased (and therefore percent solids increased) with increasing levels of both LPC and CM. While there are no universally accepted standards for the physical properties of potting substrates, desirable values for bulk density (0.20–0.75 $g\,cm^{-3}$), pH (5.2–6.3), EC ($\leq 10\,dS\,m^{-1}$), total porosity (50–85%), and substrate shrinkage (less than 30%) are generally agreed upon (Noguera et al., 2003; Sánchez-Monedero et al., 2004; Bilderback et al., 2005; Chong, 2005). All of the formulations in this study would meet these criteria, with only the percent shrinkage of the 10.0% CM treatment nearing these limits.

3.2. Tomato growth and fruit yield

SPAD values for tomato plants grown with the various treatments are shown in Table 3. SPAD meters measure the “greenness” of a plant leaf, which is directly related to the chlorophyll content of the leaves, and there is a close relationship between leaf N and leaf chlorophyll content. Gianquinto et al. (2006) found a linear relationship of SPAD values with yields of field-grown processing tomatoes, and found that below a SPAD value of 47.6 tomatoes yields were reduced. Although there was much variability in the values from week to week within treatments, there was a general

Table 4
Plant heights, number of fruit per plant, weight of fruit per plant and average fruit size.

Growth media component	Height[a] (cm)	Number[a] fruit/plant	Total fruit wt/plant[a] (g)	Average fruit wt/plant (g)
Control	201.1ab	93.5a	721.9a	7.82
2.5% lesquerella press cake	179.5b	33.2c	253.6c	7.77
5.0% lesquerella press cake	206.5ab	50.5b	399.2bc	7.95
10.0% lesquerella press cake	230.5a	86.2a	678.0a	7.93
2.5% cottonseed meal	192.7ab	58.7b	455.0b	7.88
5.0% cottonseed meal	227.8a	92.0a	715.0a	7.80
10.0% cottonseed meal	170.8b	55.4b	422.3b	7.68

[a] Means within a column followed by different letters are significantly different based on differences of least squares means at $p \leq 0.05$.

trend for higher SPAD values with increasing LPC and CM, especially towards the end of the experiments. At the conclusion of the experiment, none of treatments had SPAD values which were significantly below this threshold value, even though the yields of these treatments were substantially less than the highest yielding treatments.

Values for change in plant heights, number of fruit per plant, total fruit weight per plant and average fruit weight are shown in Table 4. ANOVA results showed no differences between the 7 treatment means for average fruit weight, but showed significant differences between treatments for plant height ($p = 0.0444$), number of fruit per plant ($p < .0001$), and the transformed values of total fruit weight ($p < .0001$). Highest values for number fruit per plant and total fruit weight were for the chemically fertilized control, the 10.0% LPC and 5.0% CM treatments. These three treatments had substrate nitrogen levels of 3.2 g N kg substrate^{-1} for the chemically fertilized control, 4.2 g N kg substrate^{-1} for the 10.0% LPC treatment, and 4.1 g N kg substrate^{-1} for the 5.0% CM treatment. The 2.5% LPC had the lowest values for both total fruit weight and fruit number. Increasing CM from 5.0 to 10.0% decreased both number of fruit and total fruit weight.

Several previous studies have found the yield of greenhouse tomatoes to be lower with organic than with inorganic fertilizers (Heeb et al., 2005, 2006). In general, organic fertilizers release nutrients more slowly than inorganic fertilizers. Nitrogen supplied by an organic fertilizer such as the seedmeals used in this experiment would be released from microbial decomposition of organic nitrogen such as amino acids into ammonium ion (NH_4^+) which can be directly taken up by the plants or further converted to nitrate (NO_3^-). Heeb et al. (2005) found that there were no differences in growth and yields in greenhouse tomatoes fed either NH_4^+ or NO_3^-, but applying nitrogen above 750 mg plant^{-1} week^{-1} increased plant biomass without increasing fruit yield. The approximately double N content of CM as compared to LPC helps explain the similar results for the 5.0% CM and 10% LPC treatments. Heeb et al. (2006) additionally concluded that nitrogen was not the only nutrient responsible for lower tomato yields and that lack of sulfur (and also possibly phosphorus) can limit fruit yield under adequate nitrogen fertilization. Although potassium content of LPC was approximately half that of CM (Table 1), no typical potassium deficiency symptoms were observed. The high sulfur content of LPC as compared to CM may be helpful in applying this nutrient at sufficient rates, although increased organic sulfur may also lead to lower pH values in potting mixes (Brady, 1974).

Organic farming, whether in the field or in a greenhouse, was defined by the USDA in 1980 as a system that excludes the use of synthetic fertilizers, pesticides and growth regulators (USDA, 1980). While there are still differences among the states, however, many seedmeals used as fertilizers are not allowed in a certified organic operation, due to two restrictions in the USDA's National Organic Program (2010) standards. The first restriction requires that seedmeal has to be pesticide free, while the second restriction requires the seedmeal to be free of genetically engineered material. For example, most cotton grown in the U.S. is genetically engineered to express the gene for the *Bacillus thuringiensis* bacterial toxin in all plant parts, which would not allow it to be used in certified organic production (Organic Materials Review Institute, 2009). The cultivars of lesquerella currently grown are not genetically modified although slow growth rates make lesquerella less competitive against weeds requiring pre- and post-emergence synthetic herbicide applications (Abbott et al., 1997). However, these herbicides are applied to the soil near the plant and it is unlikely that residues will be present in the seed and hence the resultant press cake, making it acceptable for certified organic production practices. Chemical testing of the press cake for residual pesticides may be necessary to qualify it as a certified organic fertilizer.

4. Conclusions

Lesquerella press cake, a co-product of the processing of lesquerella seeds for their oil, when applied as a component of a greenhouse potting mix, at a rate of 10.0% (w/w) produced similar numbers and weights of fruit as a conventional slow-release chemical fertilizer mixture and 5.0% (w/w) cottonseed meal, a commercially available fertilizer. Together with the results of this study on greenhouse tomatoes and because lesquerella press cake could be used in certified organic systems, increasing the potential value of the press cake co-product could help to make large-scale lesquerella production profitable.

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